RESEARCH DEPARTMENT

THE INFLUENCE OF REVERBERATION ON THE LOUDNESS OF PROGRAMME

Report No. B-071

(1960/6)

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SUMMARY

It is frequently claimed that the loudness of programme for given peak readings on a peak programme meter is dependent on the reverberation. To investigate this claim, subjective tests were carried out using music as the programme material. The method is described and the results of the tests are discussed with particular reference to their application in the control of programmes.

1. INTRODUCTION

It is stated from time to time that a passage of reproduced music sounds louder if it is accompanied by reverberation than if it is comparatively "dead" even though actual peak pressures are the same for each reproduction. Thus, Maxfield[1] states that "For a given volume range as indicated by the VU-meter, reproductions from monaural sound pickups made within the useful range have an apparent volume range nearly twice that of similar reproductions from dead pickups." In this context, 'monaural' indicates a distant balance and 'dead' indicates a microphone used to accentuate a soloist.

The same subjective effect has been demonstrated by Mr. R. Haworth, of the B.B.C. Staff Training Department,[2] who states that it is most effectively used with operatic and other performances using large numbers of performers. In other types of programme the effect is less marked, and certainly less useful.

The effect is used to reproduce exceptional climaxes after it has already been necessary to use the maximum permitted peak programme reading.

As the point of climax is reached, the microphones nearest the performers are faded down and the more distant faded up. The distant microphones may include those suitable for single-microphone reproductions, effects or audience reaction microphones, or special "atmosphere" microphones placed to receive a high ratio of reverberant to direct sound. The gains of the amplifiers and attenuators associated with the microphones are previously adjusted so that no change in the peak programme meter reading takes place.

There is, in fact, no direct support for a hypothesis that music appears louder in the presence of reverberation. It can be argued that such an effect can be expected if the objective measurements are made with a standard peak programme meter in which the rise time is very much shorter than the integration time of the ear. This does not, however, apply to the VU-meter, used by Maxfield, which has a very much greater time-constant.

Experiments were made by the B.B.C. Research Department some years ago[3] using speech as programme material. Voices recorded in a non-reverberant chamber were compared with the same voices speaking in a normal talks studio and in a reverberation room with a reverberation time falling from 5·4 sec at 250 c/s to 2·0 sec at 2500 c/s. Careful statistical analysis of the judgements of 96 observations showed no significant variation in the peak programme meter readings with studio reverberation time for equal loudness of the reproduced speech.

In view of the evident contradiction between this result and the widely-held opinion that reverberation takes part in determining loudness, it was decided to repeat the work using music as the programme material.

2. EXPERIMENTAL WORK

2.1. Programme With External Reverberation Added

The method chosen for the investigation was slightly different from that used by the previous investigators, being designed to correspond more closely with the form of the initial observation. Instead of finding the difference between peak programme meter readings with different amounts of reverberation when the two examples were equally loud, the experiment was designed to detect differences in loudness when the peak readings of the peak programme meter were the same. In this way also, the difficulty of measuring the difference between two rapidly moving peak programme meter needles was avoided.

In order to make the detection of any loudness difference between programmes as easy as possible, two extremes examples were selected for comparison using differences in reverberation greater than would ever be encountered in practice.

A block schematic diagram showing the arrangement of apparatus for these subjective tests is shown in Fig. 1. A pianola, with an AXBT ribbon microphone placed near it, was played in a small, relatively dead studio with a mean reverberation time of 0·41 sec. After amplification, two separate outputs were obtained, one being used to supply the direct channel and the other being fed to an amplifier and loud-

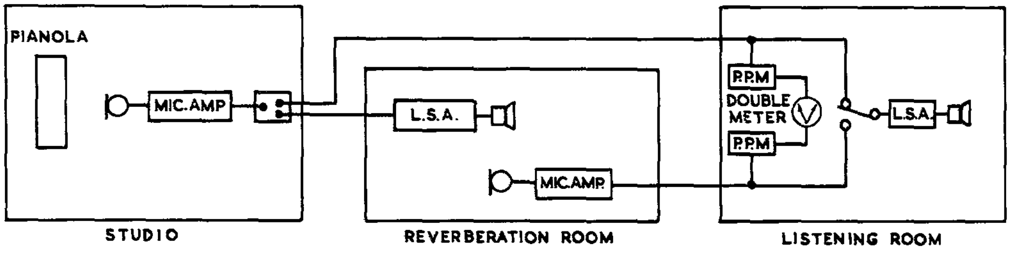

Fig. 1 - Block schematic diagram showing the arrangement of apparatus for subjective tests on loudness of music with varying reverberation

speaker in a reverberation room. An omni-directional microphone in the reverberation room and an amplifier completed the reverberant channel. This room was acoustically treated to reduce its usual long reverberation time at low frequencies and thus to avoid impairing the quality of the reverberant channel; the resulting reverberation time-frequency characteristic is shown in Fig. 2(a).

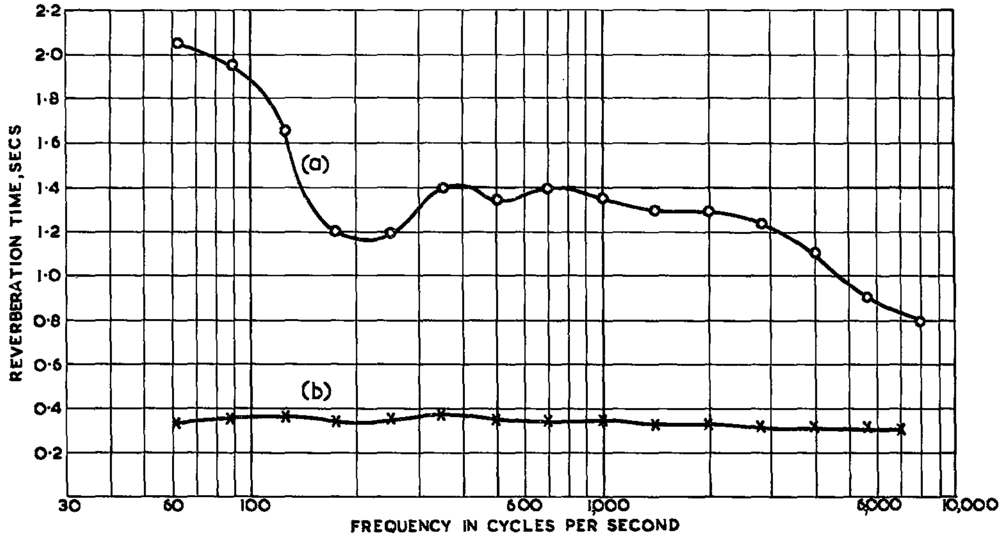

Fig. 2 - Reverberation characteristics of (a) the room used for the added reverberation and (b) of the listening room

The standard B.B.C. peak programme meter was used in this investigation. To adjust the levels of the two channels so that the peaks of each were exactly the same it was found necessary to have a peak programme meter in each channel, switching a single peak programme meter from one channel to the other being found unreliable. To facilitate the adjustment still further, a double peak programme meter was added. This is a single instrument with two movements mounted on the same axis and carrying needles of different colours. One part of this instrument was placed in series with the meter in one channel and the other part in series with the meter in the second channel. The subjects were seated, one at a time, directly in front of an LSU/10 loudspeaker, and were provided with a key to switch from one channel to the other. The listening room at Nightingale Square, which was used for the tests, has a volume of 3000 ft^3 (82 m^3) and a reverberation-time/frequency characteristic as shown in Fig. 2(b). Some subjects were allowed to set the volume control of the loudspeaker to their own preferred listening level; for the majority it was set approximately to the mean value of the levels recommended for music by Somerville and Brownless,[4] as a result of subjective tests with engineers and the general public. Each subject was asked to say which of the two channels was the louder.

The purpose of the tests was not explained in detail nor were the subjects told the difference between the two channels, though some offered comments which showed they were aware of it. Twelve subjects took part, ten male and two female. All had previously taken part in listening tests and nine were very experienced.

As a corollary to this work, an arrangement comparable to that available to studio managers was prepared. A fader was introduced into each of the channels and their outputs were mixed and applied to the listening room loudspeaker. The pianola and microphone were replaced by a tape machine, reproducing an extract of a recording, approximately one minute in duration, of an orchestral performance given in a television studio with a very short reverberation time. The tape was formed into a loop so that it could be played as many times as required without a pause. The subjects were presented with this musical extract (i) through the direct channel, (ii) through the reverberation room and (iii) with a change, at the approach of a climax, from the direct to the reverberant channel by means of the faders.

2.2. Programme with the Proportion of Inherent Reverberation Varied

In the above experiments the variation was of reverberation time, whereas in practice it is the liveness which can be altered. Therefore, before any deduction was made from the results of these experiments, it was decided that a further test should be made under conditions as close as possible to those of a studio without an echo channel.

Two ribbon microphones of the PGS type were used in Maida Vale Studio 1. One microphone was placed near the orchestra, facing it so as to receive mainly direct sound. The other was hung from a stand in the balcony with one of its minima towards the orchestra and thus received almost entirely reverberant sound. Recordings of an orchestral work were made on a twin-track tape recorder. The last minute of this piece of music, which contained a good climax, was used as the test piece.

The apparatus used for the tests was that shown in Fig. 3. Each subject was asked to watch the two pointers of the double peak programme meter and to adjust the level of one channel by means of an attenuator until both channels gave the same peak readings. Then, in the listening room, the subject heard the test piece and was asked to state which channel was the louder.

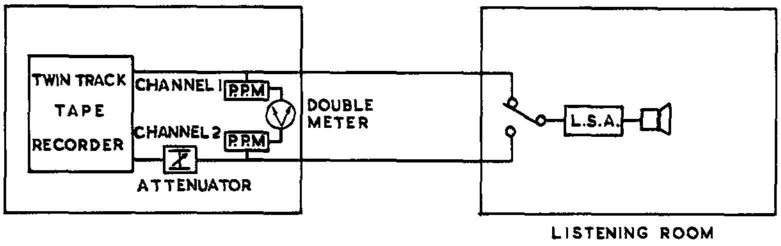

Fig. 3 - Block schematic diagram of the arrangement of apparatus for subjective tests on loudness of music with varying liveness

This whole experiment was later repeated in Riverside Studio 2 (mean reverberation time 0·85 sec) since theoretical analysis, referred to later, suggested that the effect which is the subject of the report would be more noticeable in a dead than a live studio such as Maida Vale 1 (1·8 sec mean reverberation time).

3. RESULTS AND DISCUSSION

All the experiments described above gave the same general result. Every subject decided that there was no loudness difference either between the programme with and without added reverberation (Section 2.1 above), or between the passages from close and distant microphones in the same studio (Section 2.2 above).

Several of the comments made by the subjects were of interest. Some noticed an increase in loudness after switching from the direct channel to the reverberant one but no corresponding decrease when switching back to the direct channel. This is similar to the effect of auditory adaptation,[5] but it is surprising that it should occur with signals of practically equal loudness.

Another observation was that during the quiet passages the direct channel was louder than the reverberant one although no difference was noticeable during loud passages. This may be accounted for by the greater rate of increase of loudness with loudness level at low levels than at medium and high levels, as indicated by the subjective loudness scale.[6] Thus a small difference in loudness level would produce a more easily detected loudness difference in the quiet passages than in the remainder of the programme.

The demonstration using faders to change from the direct channel to the reverberant one at the approach of a climax appeared to produce for some subjects a better climax. This, however, was not due to an increase in loudness as generally understood, but might be explained by the creation of a feeling of greatness or spaciousness, a sensation which can easily be confused with loudness. In effect, when presented with additional reverberation, the subject feels unconsciously that the sound must originate in a very large building. Therefore, for the given sound pressure, it must be a large source of sound and the suggestion of greater loudness is produced. Direct comparison by key between the two channels prevents such an interpretation and therefore gives a true comparison of loudness as ordinarily understood by those concerned with the physiology of hearing.

It was thought worth while, in view of the negative results of the loudness comparisons, to consider whether the phenomenon could be expected, in however small a degree, on theoretical considerations, having regard to the fact that the non-reverberant programme would tend to be more impulsive in nature. As the circuit controlling the rise time of the peak programme meter has a time constant of 2·5 msec while the ear has an integration time of the order of 50 msec* it is clear that the peak programme meter will have responded to a signal before the ear has decided on its loudness. Thus for very short impulsive signals the possibility of a difference in loudness with and without reverberation for the same peak programme meter reading cannot be ignored.

*The integration time of the ear has been given values by different authors ranging from 20 to 200 msec. Port[7] points out that this variation is to be expected since the hearing process cannot be represented by a simple model with one time constant. The higher figures are obtained by measurement of thresholds in the presence of masking noise and are therefore not applicable here. The most careful recent work by direct loudness comparisons gives results ranging from 23 to 50 msec. In this analysis the higher figure has been assumed as the conclusions show that this is the most conservative assumption.

Suppose a similar source is used in two rooms of reverberation times T_1 and T_2 respectively, and the signals from microphones in the two rooms are amplified so as to give the same peak reading p_o on a peak programme meter. The instantaneous output of the amplifiers at time t will then be given by

$$p_1 = p_o e^{-\alpha_1 t} \quad \text{and} \quad p_2 = p_o e^{-\alpha_2 t}$$

where $\alpha_1 = \log_e(1000)/T_1 = 6\cdot 91/T_1$ and $\alpha_2 = \log_e(1000)/T_2 = 6\cdot 91/T_2$

If the integration time of the ear is taken as 50 msec, the loudnesses of the signals are determined by the amounts E_n of energy contained in the first 50 msec of their duration,

i.e., by

$$= \int_0^{0\cdot 05} p_n^2 . dt \quad , \quad \text{where } p_n = p_o e^{-\alpha_n t} \quad ,$$

$$= p_o^2 \int_0^{0\cdot 05} e^{-2\alpha_n t} . dt$$

$$= \frac{p_o^2}{2\alpha_n} \left[1 - e^{-\alpha_n/10} \right]$$

Therefore the ratio of the energies, E_1 and E_2 of the first 50 msec of the signals from the two rooms is

$$\frac{E_1}{E_2} = \frac{\alpha_2}{\alpha_1} \left[\frac{1 - e^{-\alpha_1/10}}{1 - e^{-\alpha_2/10}} \right]$$

$$= \frac{T_1}{T_2} \left[\frac{1 - e^{0\cdot 69/T_1}}{1 - e^{0\cdot 69/T_2}} \right]$$

Fig. 4 shows how E_1/E_2 varies with T_2 for different values of T_1.

In conjunction with these tests, a determination has been made of the minimum audible difference for music (Appendix A) and this shows that the level differences must be at least 2 dB before 90% of the subjects will be able to detect a loudness difference. As the studio and reverberation room for the first test had reverberation times of 0·41 sec and approximately 1·4 sec, it can be seen from Fig. 4 that for short impulsive sounds there will be a level difference of about 2 dB. For studios with a reverberation time greater than 0·5 sec it can be seen that it would be very difficult to provide sufficient reverberation, even by artificial means, to increase the energy difference to the necessary 2 dB.

A similar analysis for signals from close and distant microphones in the same room shows that the energy differences could be greater, reaching 3 dB for the rather extreme case where one microphone is so close that the direct sound is as intense as the reverberant sound. Such a difference would be achieved only in the case of programme consisting entirely of very short impulses and is therefore not applicable to speech or music.

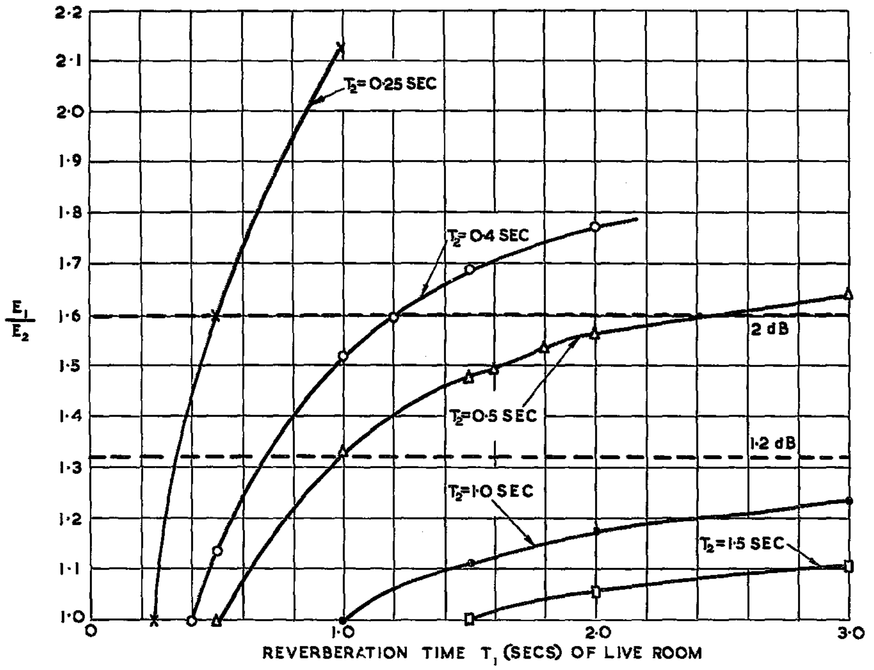

Fig. 4 - Graphs of the ratio E_1/E_2

$$= \frac{\text{Energy received in live room in first 50 msec}}{\text{Energy received in dead room in first 50 msec}}$$

Parameter T_2 = Reverberation time of dead room

4. CONCLUSION

From the results of the previous tests with speech and the present ones with music, it can be concluded that for all variations in reverberation which may be met in practice, without resource to artificial means, there is no change in loudness for a given peak programme meter reading. There is, however, a change of quality with reverberation which suggests greater loudness. This can sometimes be exploited in the reproduction of music.

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APPENDIX

MINIMUM AUDIBLE DIFFERENCES ON PROGRAMME

In view of some of the comments received while conducting subjective listening tests on loudness, it was decided to test some of the subjects to decide what level difference was necessary before they could detect a loudness difference using music as programme material. The generally accepted average minimum difference appears to be 2 dB. This value is commonly used for attenuator steps, smaller steps being deemed unnecessary as the ear would be unable to detect the change from one step to the next.

The programme selected for the test was a piece played on the pianola, of fairly constant level and with no staccato passages, isolated notes or chords. The duration of the piecewas 35 sec. The experimental arrangement is shown in Fig. 5. Two outputs were obtained from the microphone amplifier; thus the two channels used were identical except for the amount of attenuation, which could be varied in one channel. The listening level was set to be comfortable and the subjects were allowed to switch from one channel to the other whenever they wished. The time limit for each judgement was one performance of the test piece.

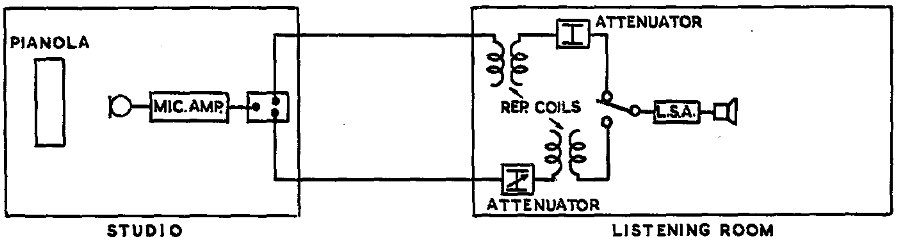

Fig. 5 - Block schematic diagram of arrangement of apparatus for determining the minimum audible level difference for subjects with music

The level difference between the two channels was varied in 1 dB steps between ±4 dB, then later in ½ dB steps between ±2 dB. The subjects were asked to say which channel was the louder but were allowed to say "equally loud" or "do not know".

The results were analysed in two ways. In the first method, at each level difference used the numbers of correct and incorrect* judgements were taken. It was then assumed that the subjects who had given incorrect judgements must have been guessing and an equal number who gave correct judgements could also have been guessing. Therefore, only the remainder of those who gave correct judgements can be regarded as reliable. The results are given in Fig. 6.

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*In subjective tests of this kind it is not usually considered permissible to describe a judgement as incorrect or as a guess, for each subject is entitled to his own opinion. However, for the purpose of this work and if such tests are to be capable of interpretation, it must be assumed that the subject's judgement cannot be relied upon if he declares that an increase in level produces a decrease in loudness, and such a judgement must be ignored or classed as a guess.

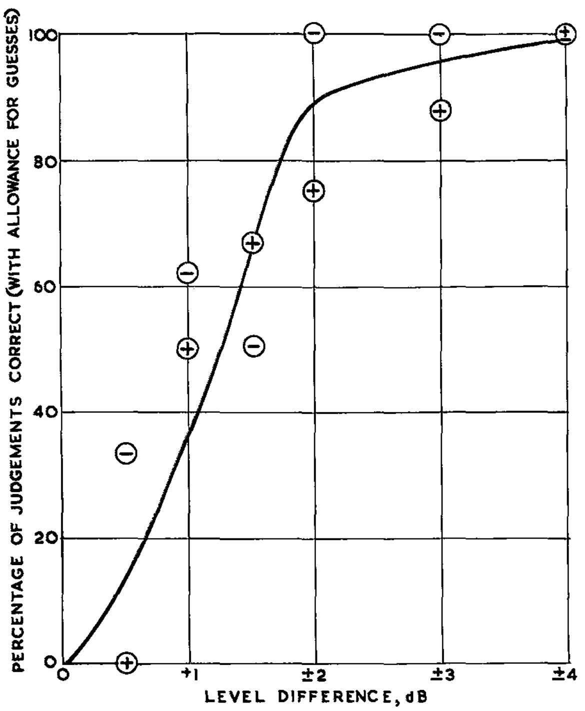

Fig. 6 - Determination of minimum audible level difference (first method)

− Higher level in channel 1
+ Higher level in channel 2

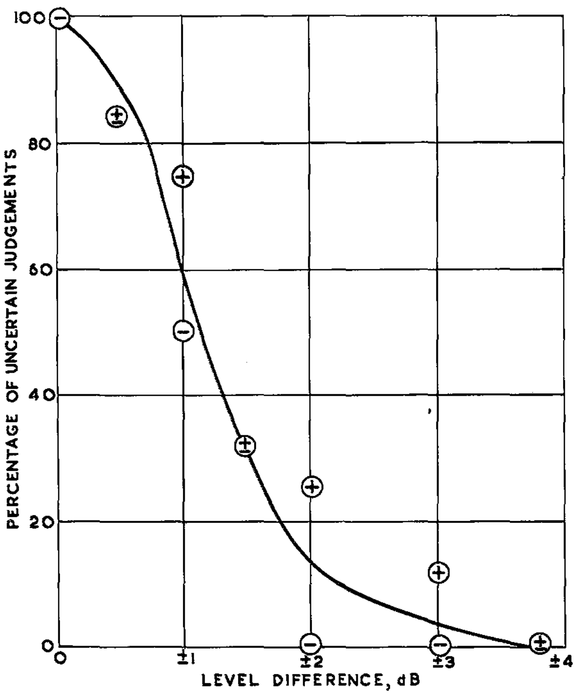

Fig. 7 - Determination of minimum audible level difference (second method)

− Higher level in channel 1
+ Higher level in channel 2

In the second method of analysis, the judgements of each subject were arranged in order of level difference as shown in the example below; 1 or 2 indicates which channel was the louder and *X* indicates equality or uncertainty.

Level difference	−4	−3	−2	−1·5	−1·0	−0·5	0	0·5	1	1·5	2	3	4	dB
Judgement	1	1	1	1	*X*	1	*X*	1	2	*X*	2	2	2	

The beginning and end of the sequence of correct results were marked and all results between these limits were designated uncertain. For each level difference the number of judgements which were uncertain was expressed as a percentage of the number of judgements made. Fig. 7 shows the results graphically.

From Figs. 6 and 7 it can be seen that with the subjects used in these tests the probability of detecting a loudness difference is 0·9 if the level difference is greater than 2 dB while 50% of the subjects can detect a difference of approximately 1·2 dB, with music as the programme material and under the test conditions of instantaneous changeover at will between the channels.

MV

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